



Technical Note

No. 222

A MINIMUM TELEMETRY RECEIVING SYSTEM FOR THE ALOUETTE TOPSIDE SOUNDER SATELLITE

Earl E. Ferguson and Richard G. Green



U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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A MINIMUM TELEMETRY RECEIVING SYSTEM FOR THE ALOUETTE

TOPSIDE SOUNDER SATELLITE

Earl E. Ferguson and Richard G. Green

A description is given of a minimum telemetry receiving system used to receive topside ionospheric records from the Alouette (S-27) satellite. Instructions are included for the determination of telemetry antenna aiming angles to the satellite from any location on the surface of the Earth.

1. Introduction

For many years, measurements of the electron density of the ionized atmospheric layers located from 80 to 500 miles above the surface of the Earth have been made from the ground by an RF pulse and echo ranging technique popularly known as ionospheric sounding. Until recently, incoherent scatter radar and sounding rockets have been the primary sources of information from above the level of maximum ion density hereafter referred to as the topside of the ionosphere. The first of a series of ionospheric sounder satellites designed to obtain data from the topside was launched on September 29, 1962. This satellite, named Alouette or S-27, has been very successful. It was constructed by the Canadian Defence Research Telecommunications Establishment, Ottawa, Ontario, and launched from the Pacific Missile Range by the National Aeronautics and Space Administration. The orbital period is 105.5 minutes, the inclination is 80.5 degrees, and the eccentricity is .002 with a perigee of 620 miles (998 km) and an apogee of 640 miles (1030 km).

Soon after launch, the simple telemetry system described herein was devised to obtain topside ionospheric data directly from the satellite when it was sounding as it passed within range of Boulder, Colorado. This system was used until a permanent CRPL telemetry station could be completed at a nearby field site.

Such a system including a suitable oscilloscope and a tape recorder --but not a camera--would cost less than \$1000. Because this system has proved satisfactory, this description has been written as a guide to other experimenters. Additional equipment which is more effective and more

expensive is also described. The report first describes the equipment used, then its operation, and finally, a relatively simple method of locating the satellite from any point on the Earth's surface.

2. Description of Equipment

A block diagram of the complete system is shown in figure 1. The antenna, meter and headphones are used by an outside operator. The remainder of the system is located with another operator inside the laboratory building. The locations are selected near enough together to insure that the 136 Mc/s transmission line is no longer than 100 feet. This relatively short distance and the use of RG-8U coaxial cable helps to minimize RF losses between the antenna and converter.

The antenna is a low cost, two meter, five element, amateur beam modified by increasing the length of each element 6%, using tight-fitting split tubing.

The 136-30 Mc/s converter was constructed locally using a Nuvistor front end and a crystal controlled oscillator to heterodyne the 136 Mc/s telemetry carrier to 30 Mc/s. The converter circuit used is shown in figure 2. Several suitable commercial units are available at reasonable cost. The converter used should have a noise figure of 3 db or better.

A popular brand commercial AM/FM receiver is used to tune to the 30 Mc/s output of the converter. The video signal is taken directly from the discriminator output through the circuit shown in figure 3. It should be noted that other converter-receiver combinations can be used. The most economical would be a converter with an output frequency of approximately

100 Mc/s connected to a standard FM broadcast receiver covering the 96 to 108 Mc/s band. The video frequencies above 10 kc/s passed by a standard FM receiver are not needed and tend to obscure the useful data. The addition of a low pass filter with a 10 kc/s cut-off will alleviate this problem.

The oscilloscope used is a popular 5" standard laboratory unit. Since only frequencies below 10 kc/s are important, any standard oscilloscope may be used. The "A-scan" of the video format of the data received from the satellite is shown in figure 4. The oscilloscope is synchronized on the negative going pulse at a sweep rate of approximately sixty-two per second.

Two methods of tape recording of the video data are used, viz., direct recording and FM.

1. Direct recording of the video data from the receiver is done at fifteen inches per second tape speed using a $\frac{1}{4}$ inch width two-track tape. The data are recorded on one track, and WWV is recorded on the other. The frequency response of many ordinary tape recorders at this speed will be from 50 c/s to 15,000 c/s, which will be more than adequate for this purpose; however, a slight loss will be shown in the frequency markers and plasma phenomena which lie below the 50 c/s range.

2. FM recording of the video data from the receiver is done on one track at fifteen inches per second tape speed using a 27 kc/s subcarrier. WWV as a time reference is directly recorded on the second track. The recorder used is a professional type with $\frac{1}{2}$ inch tape and FM record and playback modules. The FM method of recording has a frequency response from DC (zero c/s) to 5000 c/s at 15 inches per second. No appreciable loss

to any part of the record has been found. This method is superior to but more expensive than the direct method.

While the recorded tape may be run as many times as desired, this will yield only a temporary picture on the oscilloscope. To obtain permanent records that can be studied at leisure, it is necessary to record the data on film.

A convenient method is to use a B-scan mode by modulating the Z axis of the oscilloscope with the video data. This B-scan is then photographed with a moving-film camera to produce ionograms such as are shown in figures 5a and b. Normally the film rate may be between five and twenty inches per minute. The record in figure 5a was made with a film rate of twenty inches per minute, and the data were taken from an FM recorded tape. Figure 5b shows a record taken from a direct recorded tape at fifteen inches per second tape speed, and a film rate of twenty inches per minute. Either record is useful. However, in the directly recorded data a loss of low frequency response is revealed by the poor frequency marker and plasma resonance indications. The ionograms shown in figures 5a and b were not taken at the same time, thus are not identical; also, the high frequency portions of the ionograms have been masked for reproduction purposes. The 100 km range markers seen on the ionograms, figures 5a and b, are generated by a local oscillator/pulse generator synchronized to the transmitted pulse and external to the equipment shown in the block diagram. The frequency markers are generated in the satellite.

3. Operation

This system can be operated by two persons, one to aim the antenna and the other to check receiver and tape recorder operation. As seen in figure 6, the antenna is held by an operator who wears headphones carrying the video signal from the receiver audio output. The operator also holds a meter which indicates the AGC voltage from the receiver. At the predicted time of start of pass and satellite turn on, the operator points the antenna at the predicted azimuth and elevation. While a satellite telemetry station does not usually turn on a satellite at less than fifteen degrees above the horizon, it has been proven in practice that it is possible to follow S-27 from horizon to horizon with the system described in this report. Extreme accuracy is not necessary due to the relatively large beamwidth of the antenna and strong 136 Mc/s signal from the satellite. Plus or minus fifteen degrees accuracy is adequate. The operator identifies the signal from the characteristic sound of the sounder transmitter pulses in the headphones and aims and rotates the antenna about its longitudinal axis for maximum signal level indication on the meter. He follows the satellite with the antenna during the pass, constantly checking the rotation of the antenna about its axis to compensate for polarization shifts in the downcoming signal. There is usually at least a ninety degree rotation in received polarization during any one pass.

The second operator stationed at the receiver adjusts the receiver tuning so that the video signal "A-scan" on the oscilloscope (figure 4) shows approximately equal negative-going sync pulses and positive-going sounding-transmitter pulses (base line centered). Once adjusted at the

start of a pass, the receiver should not have to be retuned.

4. Description of Satellite Operation

Following a turn-on command by a ground telemetry station the ionospheric sounder in the satellite will operate for a little less than ten minutes. During this time the ionospheric echoes are placed on a 136.077 Mc/s FM link by direct FM modulation of the carrier. This information is received by the ground station and recorded on magnetic tape. When these data are transferred to 35mm film, approximately thirty-two ionograms result from each ten minute run. Each ionogram requires eighteen seconds for completion and during this eighteen seconds the sounder in the satellite sweeps from 0.5 Mc/s to 11.5 Mc/s and returns to 0.5 Mc/s.

During the first year, S-27 produced approximately 423,000 ionograms. As noted above, the satellite does not sound continuously throughout every orbit. It operates only during the ten minute turn-on periods. Satellite power restrictions as well as the location of the telemetry command stations are both limiting factors. Since the launch of S-27 on September 29, 1962, the number of ten-minute turn-ons has averaged thirty-five daily. Of this number, two to five turn-ons have been for the purpose of VLF experiments which are not usable for ionospheric sounding data. To give some idea of the frequency pattern of the turn-ons, we have indicated in figure 7 the actual ionosonde data portions of satellite tracks for a one week period. This gives some indication of the probability of finding the satellite turned on for any particular pass. The satellite is turned on during most passes over North America.

5. Prediction of Telemetry Antenna Aiming Angles

A simple, semi-graphical method for determining the local elevation and azimuth of Alouette is used. Essentially the method consists in first constructing an elevation-azimuth grid for the observing location on a base map of the world having a scale of 1/70,000,000 or better. Then an overlay of the satellite track is placed on this map to determine the satellite track relative to the observer. Equatorial crossings data provide a means for locating the satellite at any instant. Here it is assumed that the satellite has a very low eccentricity and that the geocentric angular velocity is nearly constant. Such an assumption of a circular orbit will produce a maximum error in time of less than 0.3 min, an error of less than 1° in elevation, and a very small error in azimuth.

To construct the elevation grid one must compute the elevation angle E corresponding to various positions of the satellite. Assume that the Earth is a perfect sphere of radius 6378 km and that the height of Alouette is 1028 km. Then the relation

$$R = 90 - \left(\arcsin \frac{6378}{1028 + 6378} \cos E + E \right) \quad (1)$$

gives the angular distance R between the observing station and the satellite (see figure 8). Values of R for elevations between 0 and 75 degrees are given in the table below. The quantity $R(\text{km})$ is the surface distance from the station to the subsatellite point.

E	0°	15°	30°	45°	60°	75°
R	30.67°	18.71°	11.77°	7.49°	4.49°	2.12°
R(km)	3410	2080	1310	830	500	240

The speediest procedure for plotting the elevation angle grid is to describe on a globe circles of the prescribed radius about the station, after which the geographic coordinates can be read in order to transfer the circles to the working base map.

If preferred, the coordinates may be calculated directly from the cosine formula for spherical triangles

$$\cos \Delta \lambda = (\cos R - \sin \varphi_s \sin \varphi) \sec \varphi_s \sec \varphi \quad (2)$$

where $\Delta \lambda$ = the difference in longitude between the observer and a point on the circle of elevation grid,

φ_s = the observer's latitude,

φ = the assumed latitude of any circle of elevation grid point, and

R = the radius of a circle of elevation in degrees.

An azimuth grid may be made while carefully holding a circular protractor on the globe, tangent at the station. Azimuth lines every 30° or so can thus be transferred to the base map. To compute these lines, however, take the following as derived from the cosine formula for spherical triangles:

$$\tan\varphi = (\sin\Delta\lambda \cot A + \cos\Delta\lambda \sin\varphi_S) \sec\varphi_S \quad (3)$$

where $\Delta\lambda$ = the difference of longitude between the observer and a point on an azimuth line,

φ = the latitude of the point,

φ_S = the observer's latitude as before, and

A = the azimuth.

(An elevation and azimuth grid map prepared for Boulder, Colorado, is shown in figure 9.)

Next a tracing paper overlay of the satellite track (such as figure 10) is prepared for use with the base map. This is made from the geographic position of the satellite every minute through one revolution as is given below in table 1. Note that we have used a fictitious reference longitude of 0° at the zero time instant of S-N equator crossing, and that the longitudes increase as the satellite moves towards the east.

Table 1. Geographic Position of Satellite Through One Revolution

Time (Min)	Lat.	Long.	Time (Min)	Lat.	Long.	Time (Min)	Lat.	Long.	Time (Min)	Lat.	Long.
0	0.0	0.0	27	80.3	95.3	54	- 3.9	167.1	81	-78.8	282.4
1	3.3	0.3	28	79.1	112.8	55	- 7.2	167.4	82	-76.6	294.7
2	6.7	0.6	29	77.1	125.9	56	-10.6	167.7	83	-74.1	303.3
3	10.1	1.0	30	74.6	135.1	57	-14.0	168.1	84	-71.2	309.4
4	13.5	1.3	31	71.8	141.6	58	-17.4	168.4	85	-68.3	313.8
5	16.9	1.7	32	68.9	146.3	59	-20.7	168.8	86	-65.2	317.2
6	20.3	2.0	33	65.8	149.9	60	-24.1	169.2	87	-62.0	319.8
7	23.7	2.4	34	62.7	152.6	61	-27.5	169.7	88	-58.8	321.8
8	27.0	2.9	35	59.5	154.7	62	-30.8	170.2	89	-55.6	323.5
9	30.4	3.4	36	56.3	156.5	63	-34.2	170.7	90	-52.3	324.9
10	33.7	3.9	37	53.0	157.9	64	-37.5	171.3	91	-49.0	326.0
11	37.1	4.5	38	49.7	159.1	65	-40.8	172.0	92	-45.7	327.0
12	40.4	5.2	39	46.4	160.1	66	-44.2	172.8	93	-42.4	327.9
13	43.8	5.9	40	43.2	160.9	67	-47.5	173.7	94	-39.0	328.6
14	47.1	6.8	41	39.8	161.7	68	-50.8	174.8	95	-35.7	329.2
15	50.4	7.9	42	36.5	162.4	69	-54.1	176.0	96	-32.3	329.8
16	53.6	9.1	43	33.2	162.9	70	-57.4	177.5	97	-28.9	330.3
17	56.9	10.6	44	29.8	163.5	71	-60.6	179.4	98	-25.6	330.8
18	60.1	12.4	45	26.5	163.9	72	-63.8	181.7	99	-22.2	331.2
19	63.3	14.6	46	23.1	164.4	73	-66.9	184.7	100	-18.8	331.6
20	66.4	17.5	47	19.8	164.8	74	-69.9	188.7	101	-15.4	332.0
21	69.5	21.2	48	16.4	165.1	75	-72.8	194.0	102	-12.0	332.3
22	72.4	26.2	49	13.0	165.5	76	-75.6	201.4	103	- 8.6	332.7
23	75.1	33.2	50	9.6	165.8	77	-77.9	211.9	104	- 5.2	333.0
24	77.5	43.0	51	6.2	166.1	78	-79.6	226.7	105	- 1.8	333.3
25	79.4	57.0	52	2.9	166.5	79	-80.5	245.7	105.4	0.0	333.5
26	80.4	75.2	53	- 0.5	166.8	80	-80.1	265.7			

The final step in local azimuth and elevation determination is to refer to a current NASA Goddard Space Flight Center four-part bulletin for 62 Beta-Alpha 1 (Alouette) (available to investigators by writing that agency at Greenbelt, Maryland 20771) that provides the Universal Time and West Longitude of each S-N equator crossing. A portion of such a bulletin is reproduced here in table 3. As an example, we have selected Revolution 8645 as seen from Boulder on 23 June 1964. The table gives the time and longitude of equator crossing as 1748.37 UT and 275.7°W. We now find that if the "zero" end of the satellite track overlay is placed at 275.7°W we may write down the following information on this pass as shown in table 2.

Table 2. Predicted Telemetry Antenna Aiming Angles

<u>Time (UT)</u>	<u>Az.</u>	<u>El.</u>
18 ^h 20 ^m	343°	0°
22	340	6
24	335	15
26	324	28
28	294	44
30	240	45
32	210	28
34	198	15
36	192	6
38	189	0

Note that the weekly soundings are cyclic in nature. As may be verified by reference to the table of equatorial crossings, the satellite will appear at the same longitude of equatorial crossing (to within 0.1°) at intervals of 6^d 23^h 04.8^m, or 95 revolutions. This means that each Alouette pass observed at any one station will be repeated one week later less 55.2 minutes.

6. Acknowledgments

The authors are indebted to Mr. James M. Watts for the initiation of this system and to Mr. Leray LaBaume for his assistance in the development and operation of the final system.

Table 3. Alouette S-N Equator Crossings

REV	TIME Z	LONG W	REV	TIME Z	LONG W	REV	TIME Z	LONG W
18 JUN 64								
8576	1627.18	245.45	8577	1812.72	271.98	8578	1958.24	298.50
8579	2143.77	325.03	8580	2329.29	351.55			
19 JUN 64								
8581	114.82	18.08	8582	300.34	44.60	8583	445.86	71.13
8584	631.39	97.65	8585	816.91	124.18	8586	1002.44	150.70
8587	1147.96	177.23	8588	1333.49	203.75	8589	1519.01	230.28
8590	1704.53	256.80	8591	1850.06	283.33	8592	2035.58	309.86
8593	2221.11	336.38						
20 JUN 64								
8594	6.63	2.91	8595	152.16	29.43	8596	337.68	55.96
8597	523.20	82.48	8598	708.73	109.01	8599	854.25	135.53
8600	1039.78	162.06	8601	1225.30	188.58	8602	1410.83	215.11
8603	1556.35	241.63	8604	1741.88	268.16	8605	1927.40	294.68
8606	2112.92	321.21	8607	2258.45	347.73			
21 JUN 64								
8608	43.97	14.26	8609	229.50	40.79	8610	415.02	67.31
8611	600.55	93.84	8612	746.07	120.36	8613	931.59	146.89
8614	1117.12	173.41	8615	1302.64	199.94	8616	1448.17	226.46
8617	1633.69	252.99	8618	1819.22	279.51	8619	2004.74	306.04
8620	2150.26	332.56	8621	2335.79	359.09			
22 JUN 64								
8622	121.31	25.61	8623	306.84	52.14	8624	452.36	78.67
8625	637.89	105.19	8626	823.41	131.72	8627	1008.93	158.24
8628	1154.46	184.77	8629	1339.98	211.29	8630	1525.51	237.82
8631	1711.03	264.34	8632	1856.56	290.87	8633	2042.08	317.39
8634	2227.60	343.92						
23 JUN 64								
8635	13.13	10.44	8636	158.65	36.97	8637	344.18	63.49
8638	529.70	90.02	8639	715.23	116.54	8640	900.75	143.07
8641	1046.27	169.60	8642	1231.80	196.12	8643	1417.32	222.65
8644	1602.85	249.17	8645	1748.37	275.70	8646	1933.90	302.22
8647	2119.42	328.75	8648	2304.95	355.27			
24 JUN 64								
8649	50.47	81.80	8650	235.99	48.32	8651	421.52	74.85
8652	607.04	101.37	8653	752.57	127.90	8654	938.09	154.42
8655	1123.62	180.95	8656	1309.14	207.48	8657	1454.66	234.00
8658	1640.19	260.53	8659	1825.71	287.05	8660	2011.24	313.58
8661	2156.76	340.10	8662	2342.29	6.63			
25 JUN 64								
8663	127.81	33.15	8664	313.33	59.68	8665	458.86	86.20
8666	644.38	112.73	8667	829.91	139.25	8668	1015.43	165.78
8669	1200.96	192.30	8670	1346.48	218.83	8671	1532.00	245.35
8672	1717.53	271.88	8673	1903.05	298.41	8674	2048.58	324.93
8675	2234.10	351.46						
26 JUN 64								
8676	19.63	17.98	8677	205.15	44.51	8678	350.67	71.03
8679	536.20	97.56	8680	721.72	124.08	8681	907.25	150.61
8682	1052.77	177.13	8683	1238.30	203.66	8684	1423.82	230.18
8685	1609.34	256.71	8686	1754.87	283.23	8687	1940.39	309.76
8688	2125.92	336.29	8689	2311.44	2.81			

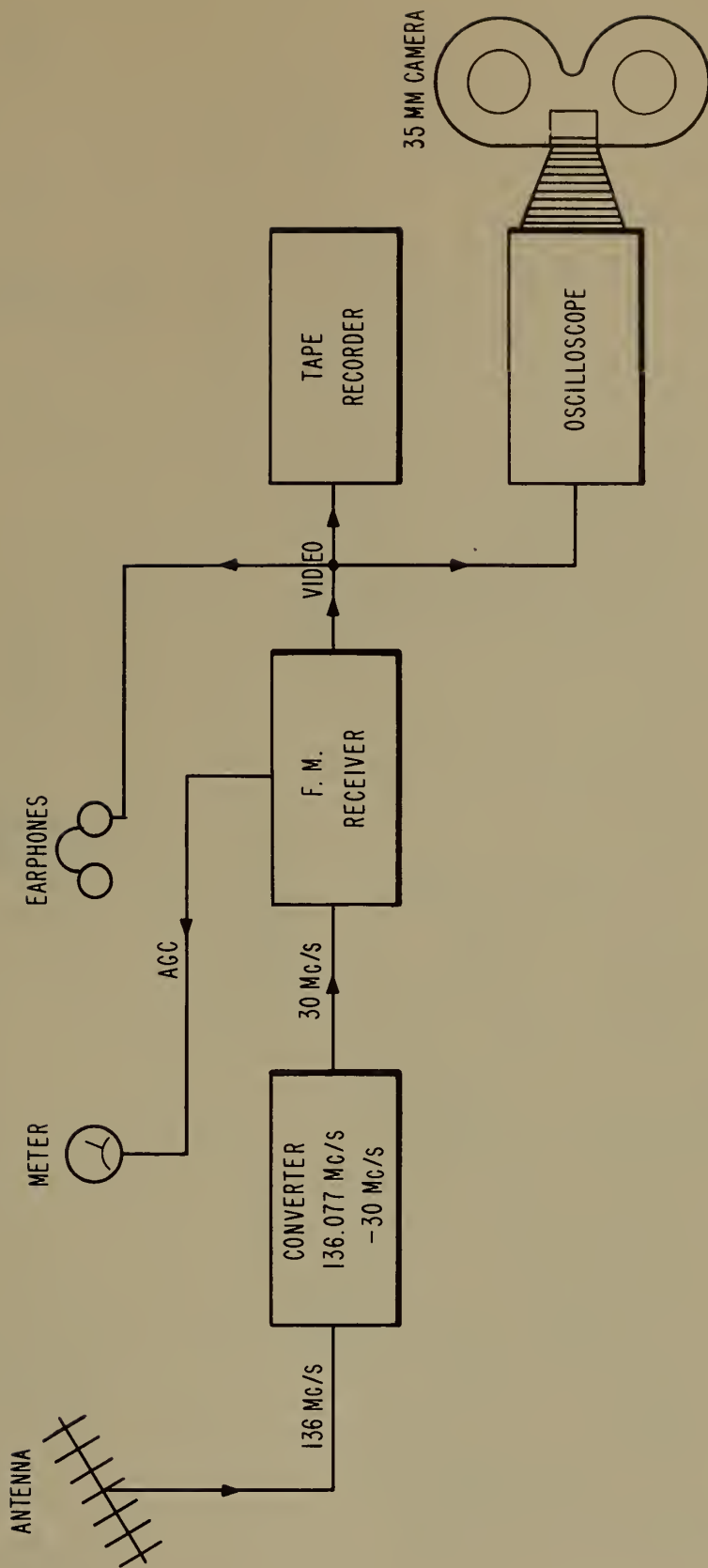


FIG. 1. TELEMETRY SYSTEM



FIG. 2. CRYSTAL CONTROLLED CONVERTER

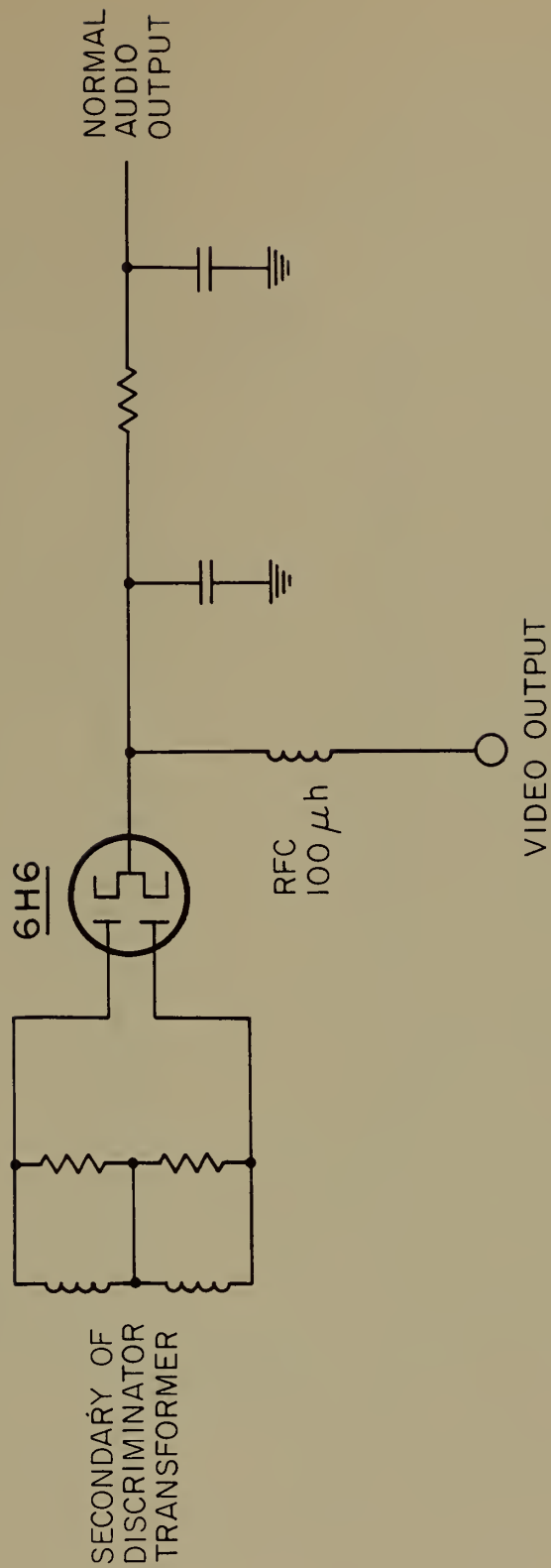


FIG. 3. CONNECTION TO DISCRIMINATOR

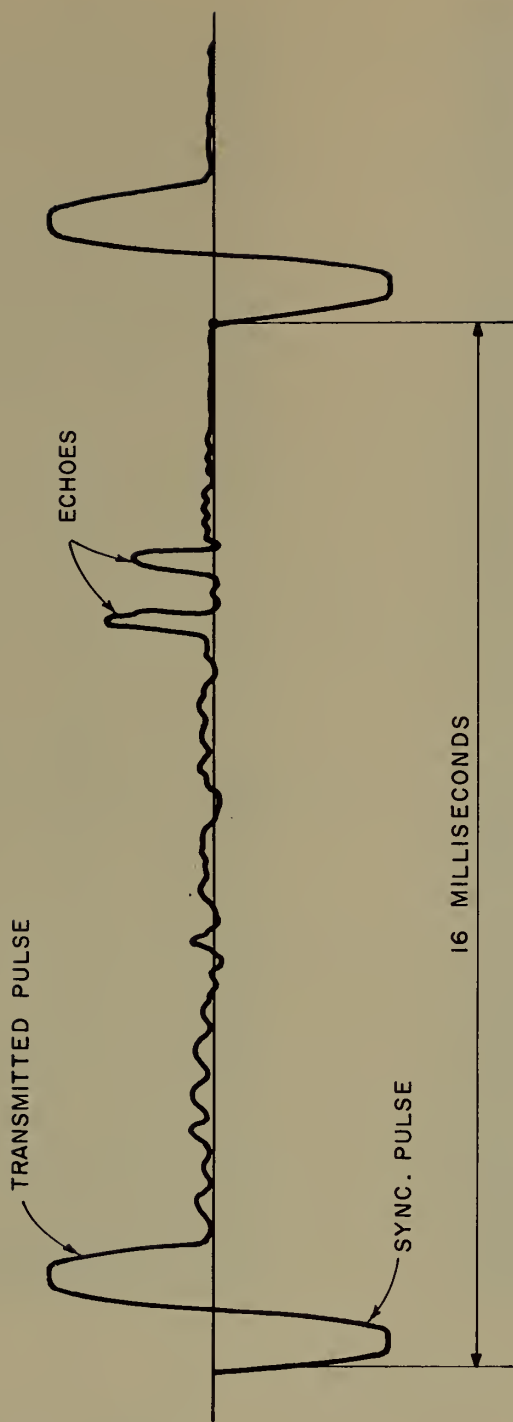


FIG. 4. VIDEO FORMAT

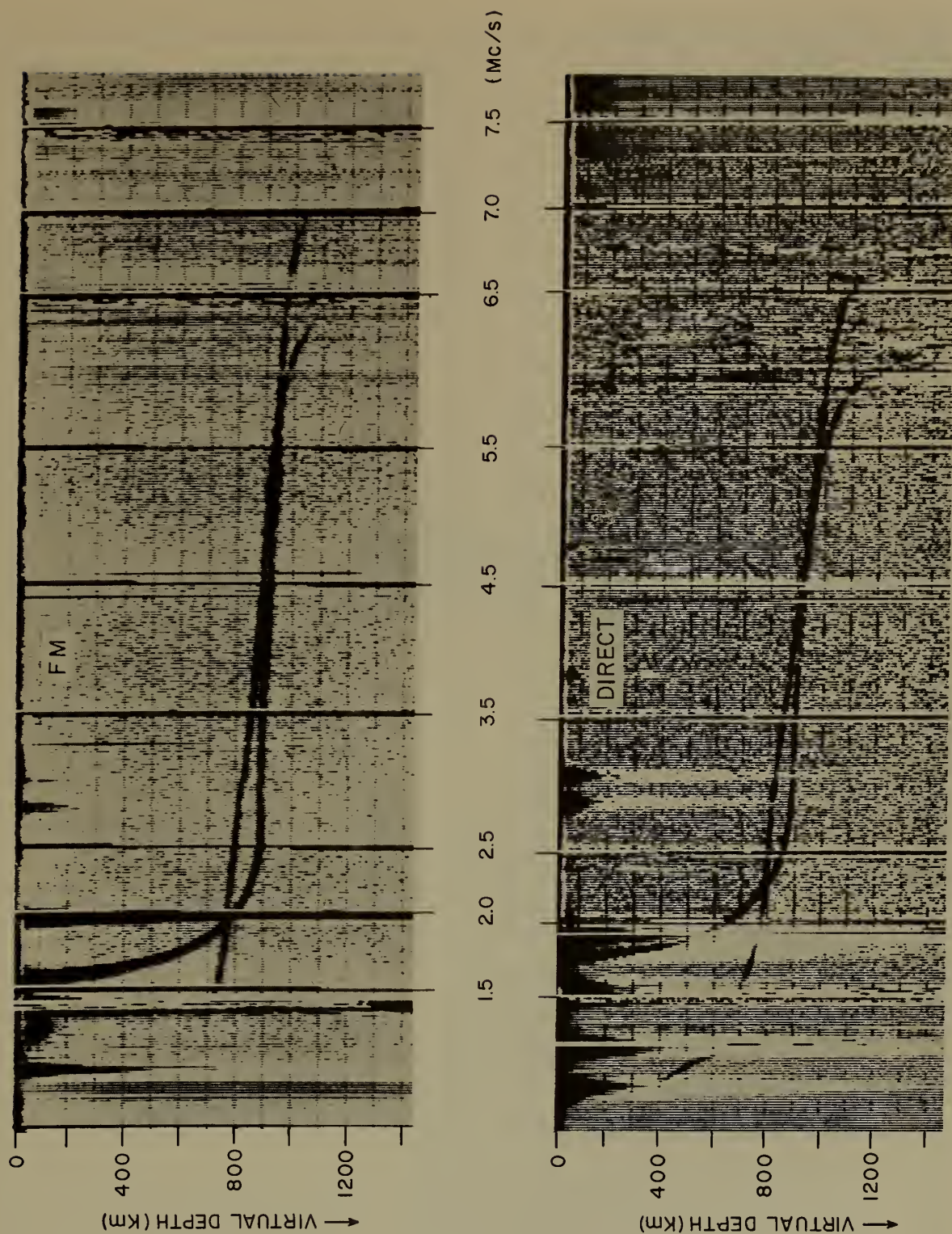


FIG. 5. FM AND DIRECT RECORDED IONOGRAMS



FIG. 6. OPERATOR TRACKING SATELLITE

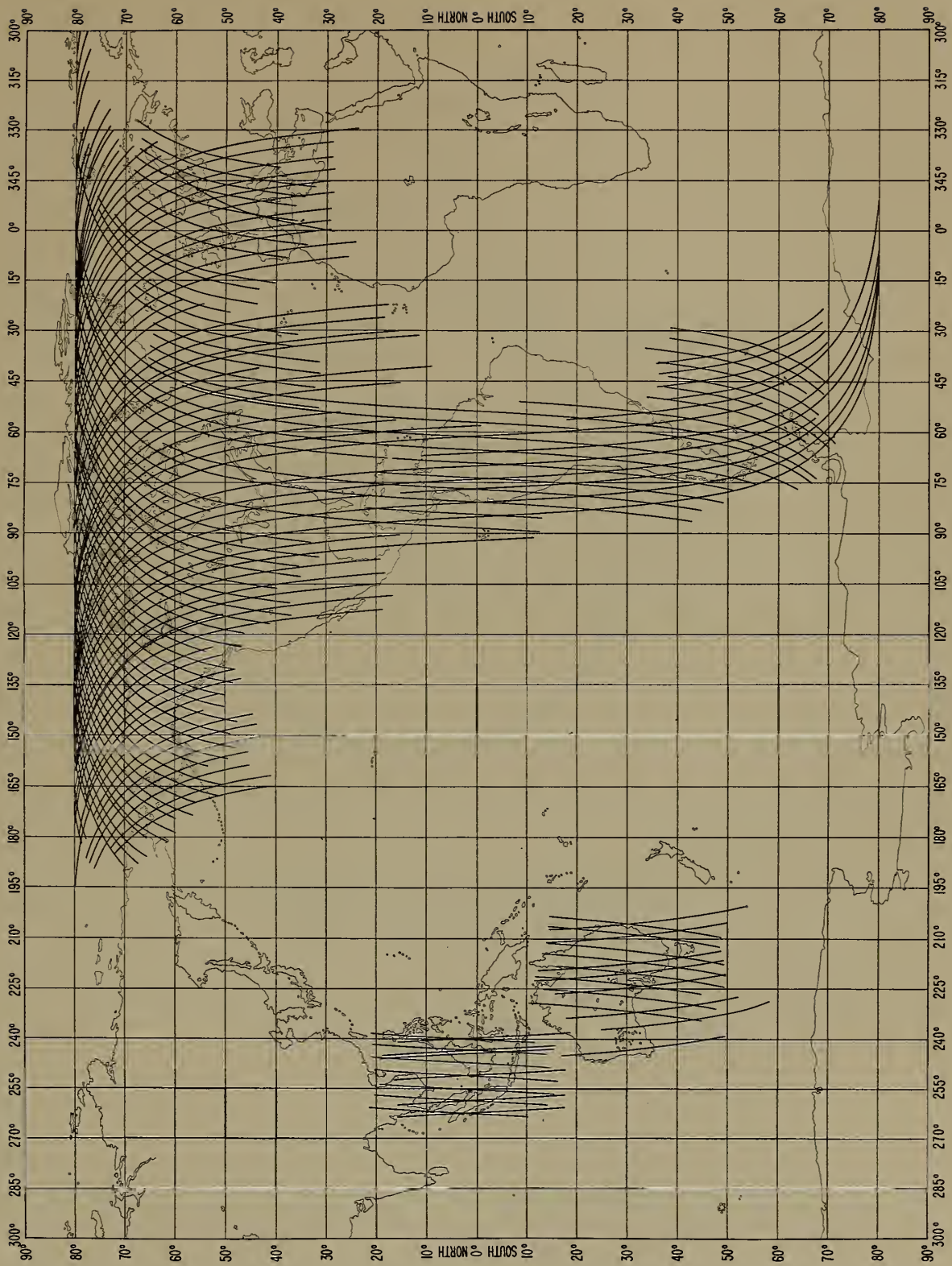


FIG. 7. LOCATION OF SATELLITE DURING TURN-ON FOR ONE WEEK

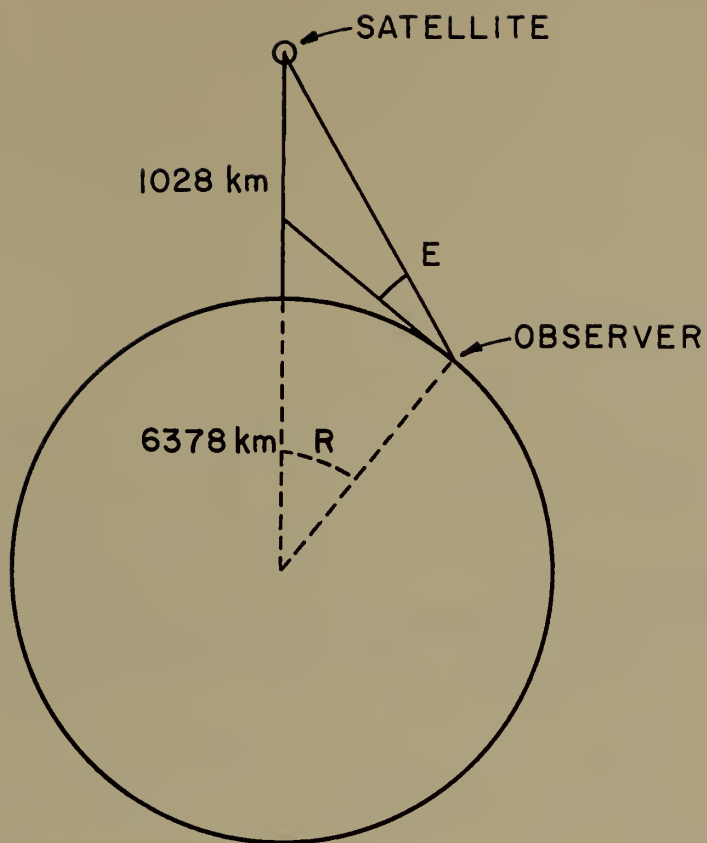


FIG. 8. GEOMETRY FOR DERIVATION
OF EQUATION 1

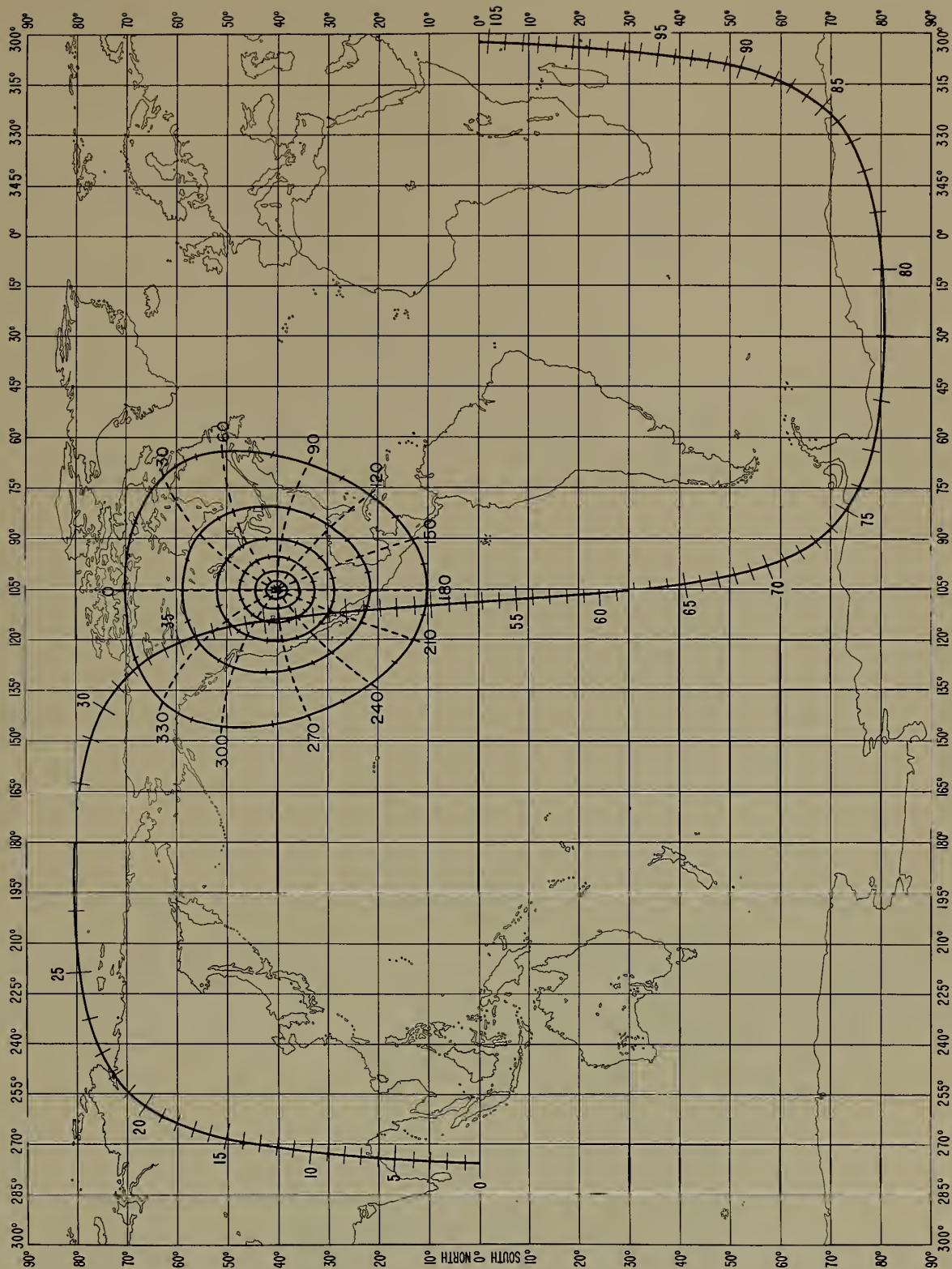


FIG. 9. BASE MAP WITH OBSERVER'S ELEVATION-AZIMUTH GRID
AND SATELLITE TRACK

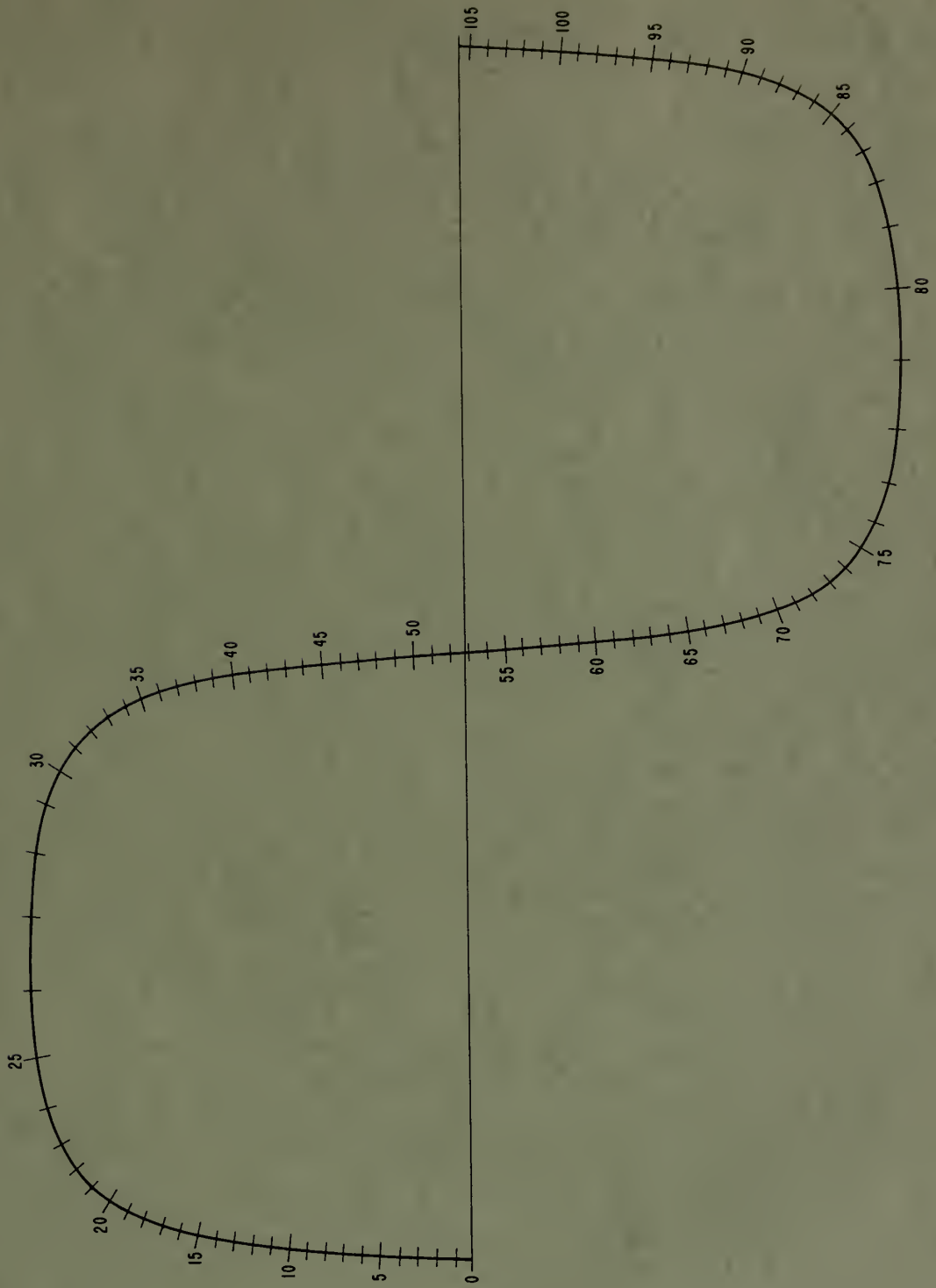


FIG. 10. SATELLITE TRACK OVERLAY

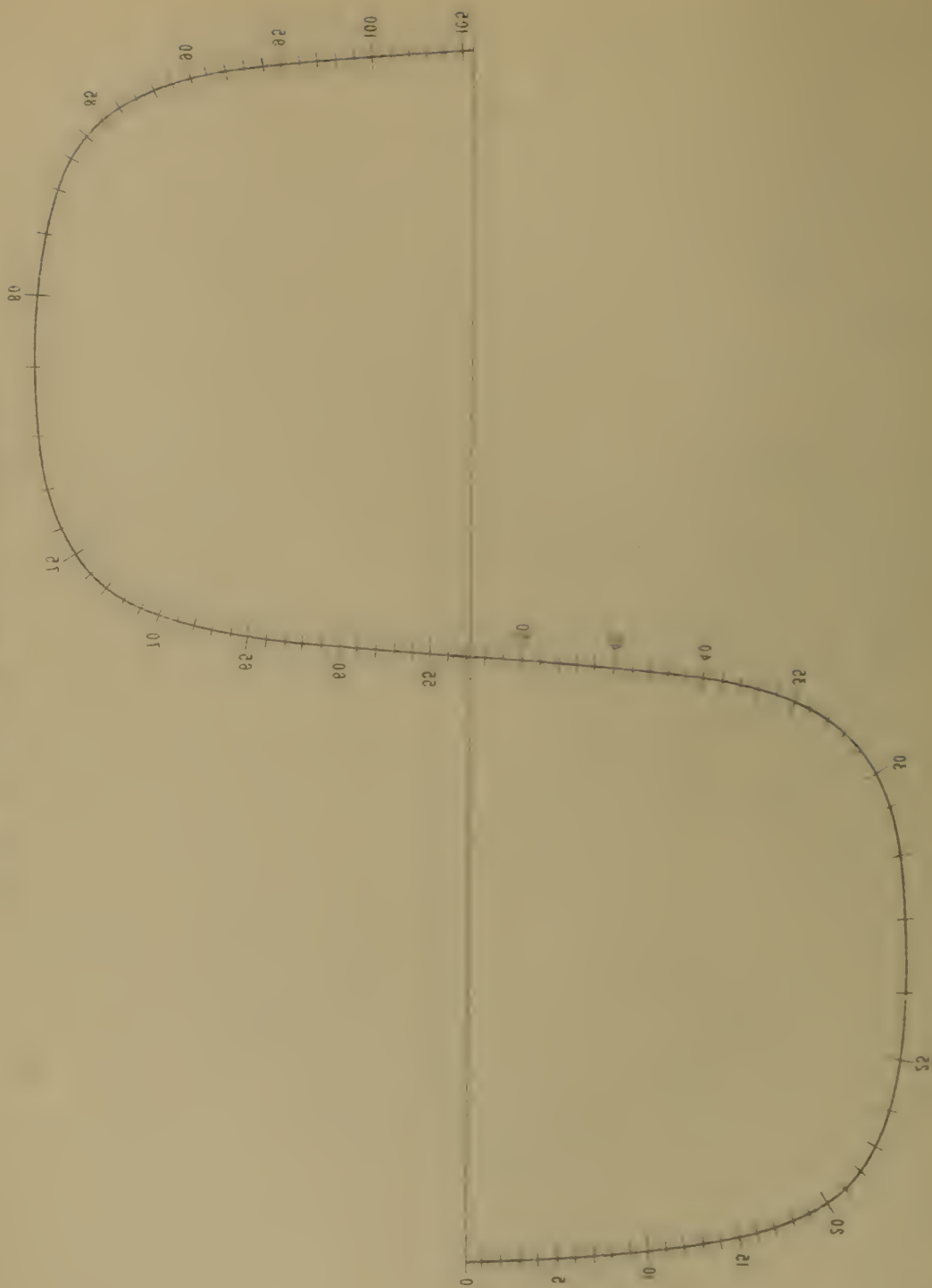


FIG. 10. SATELLITE TRACK OVERLAY

